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November 14, 2011

Review of the technical report on the scientific basis for alternative San Joaquin River flow objectives for the protection of fish and wildlife beneficial uses and program of implementation, for the California State Water Resources Control Board.

Below, I review the first two parts of the technical report, hereafter referred to as "the report". The relevant issues that reviewers are tasked with assessing are listed (see Table 1). I focused mainly on Part 3, which is the area best aligned with my expertise (issues #2-5), with only a brief review of Part 2, which addressed issue #1 (Table 1). In some cases, my review is of the primary studies or documents on which the report relies. My review considered the degree of support from scientific literature (were all relevant studies cited), how appropriate statistical analyses were and whether they supported conclusions drawn in the report.

Table 1. List of issues to be addressed by this review.

1. Adequacy of the Technical Report's hydrologic analysis of the San Joaquin River basin comparing unimpaired flow with actual observed flows in representing changes that have occurred to the hydrograph of the San Joaquin River basin in order to provide background and support for the remaining chapters…
2. Determination that changes in the flow regime of the San Joaquin River basin are impairing fish and wildlife beneficial uses.
3. Appropriateness of the approach used to develop San Joaquin River flow objectives for the reasonable protection of fish and wildlife beneficial uses and the associated program of implementation.
4. Determination that more flow of a more natural spatial and temporal pattern is needed from the three salmon-bearing tributaries to the San Joaquin River during the February through June time frame to protect San Joaquin River fish and wildlife beneficial uses.
5. Appropriateness of using a percentage of unimpaired flow, ranging from 20 to 60 percent, during the February through June time frame, from the Stanislaus, Tuolumne, and Merced Rivers as the proposed method for implementing the narrative San Joaquin River flow objective.

Part 2. Hydrologic Analysis of San Joaquin River Basin

The purpose of this section is to address **issue #1 (Table 1**) by presenting evidence that a significant fraction of unimpaired flows into the San Joaquin tributaries and mainstem are stored and diverted as consumptive uses of water. These reductions in flow and alterations to flow regime are quantified. To summarize, overall annual flow have been frequently been less than half of unimpaired flows. Specifically, median annual flows were reduced to 44% of unimpaired annual flows since 1930. A physical manifestation of the magnitude of change in peak flows has been formation of a new, much lower floodplain in some tributaries (Cain et al. 2003).

In addition to documenting changes in the annual quantity of flow, the report cites seasonal shifts in timing of the remaining in-stream flows (McBain and Trush 2002; Cain et al. 2003). The reduction in spring and early summer snowmelt flows has been the most significant alteration to SJ flow regimes. Regulated flow regimes exhibit a lower frequency and intensity of late-fall and winter storm flows. Consequently, hydrologic variability is considerably lower than it would otherwise be (Cain et al. 2003). A larger proportion of regulated annual flow occurs during summer and fall, but the absolute magnitude may not differ from unimpaired flow regimes.

I concur that the Technical Report's hydrologic analysis is adequate and consistent with previous studies. The analysis demonstrated that significant changes to the San Joaquin basin flow regimes result from post-dam upstream water uses. Areas of uncertainty include the magnitude of evapotranspiration from wetland riparian species and groundwater return flows from agriculture. Nevertheless, the main result regarding the substantial differences between unimpaired and post-dam San Joaquin basin flows appears to be clear-cut and well supported.

Part 3. Scientific Basis for Developing Alternate San Joaquin River Flow Objectives

Part 3 addresses issues #2-5 (Table 1). It provides support for the argument that impaired flows have been insufficient to support the freshwater phase of fall Chinook salmon and steelhead populations and has put them at high risk of extinction. The report does a good job of presenting relevant past research carried out by California agencies to support the conclusion that water development is impairing salmon production. The flow-salmon relationship is well-documented. However, the flow-salmon relationship is dominated by indirect pathways mediated by other factors, and the remaining uncertainties involve parsing out proximate factors that link flow to salmon and steelhead status and trends. In the review below, I cited additional relevant and published research for consideration by the authors.

Assessment of extinction risk

The report provides an assessment of extinction risk based on a recent framework proposed for the Central Valley salmonids by Lindley et al. (2007). Lindley et al. (2007) set out criteria for assessing risk for salmon and steelhead based on status, trends, catastrophes, and hatchery influence, many of which build on an earlier report by McElhaney et al. (2000). Both sources are generally consistent with generally accepted scientific principles of conservation biology, but await scientific scrutiny by reviewers for a higher tier journal. They concluded that data were insufficient to assess viability of Central Valley steelhead. Mesick (2009) applied the Lindley et al. criteria in an assessment of risk for fall Chinook salmon and concluded the population is at high risk according to some criteria (high risk was defined as 20% risk of extinction [of natural spawners] within 200 y) and moderate risk according to others. Four factors that Lindley et al. used to define populations at high risk of extirpation were (1) prolonged low spawner abundances (<250) over a generation, (2) a precipitous (>10%/y) declining trend in abundance, (3) catastrophic decline of >10% in one generation during the past ten years, and (4) high hatchery influence, as summarized and commented on below.

(1) **Status**: To assess status, Mesick (2009) adjusted escapement to represent only wild spawners (rather spawners with >=1st generation wild parents). These numbered fewer than 250 for longer than one 3-y generation. Consequently, more than one brood year was affected. Without stocking or straying of adults from nearby rivers, the risk of local extirpation during these extended troughs was, and will continue to be, very high.
(2) **Declining trend**: By 2000, Tuolumne River spawner abundances had already experienced a negative 40-y trend (Jager 2000). Since that time (1999-2008), natural spawners in the SJB have declined at an average rate of 19% per year (Mesick 2009). A viable population should have a Natural Return Ratio (NRR) >=1 (McElhaney 2000). Early indications are that this year may be slightly better than last.
(3) **Catastrophe**: Mesick focused on the recent extended drought as a catastrophe. A large, order-of-magnitude decline occurred between the 2000-2002 generation and the 2003-2005 generation of spawners. In my experience with assessing future risk, past catastrophes are important mainly because of what they portend about the future. Past events can be used to quantify the frequency, magnitude, and duration of future events to aid in PVA modeling and recovery planning. I am not sure I agree with the use of a recent catastrophe as strong evidence for future risk except in the short term (see Allee effect discussion below).
(4) **Hatchery influence**: The recovery goal is a wild population and not a captive-breeding population on life support. Over 20% of Tuolumne River fall Chinook salmon is of 1st-generation hatchery origin. This exceeds a model-based threshold of 10% that McElhaney (2000) derived based on a model analysis. Ensuring that hatchery inputs are at least an order of magnitude smaller than population growth rate reduces the correlation between the hatchery and wild populations. Hatchery returns and in-river

spawner abundances are highly correlated (see figure 20 in Lindley et al. 2009) so that the hatchery inputs are highest when they are least needed and possibly, most harmful (density-dependent effects).

The report made the case that the San Joaquin Basin (SJB) fall Chinook ESU is at risk, as summarized above. In this case, the risk is fairly clear. How immediate is the risk? A population viability analysis (PVA) is needed to quantify the distribution of future times to extinction of the 'wild' population. Note that the conclusions above are consistent with my unpublished PVA for the Tuolumne River (Jager 2000).

Below are some suggestions that the report authors might consider incorporating into their framework. Population viability is usually assessed in terms of **abundance**, **productivity, spatial extent**, and **diversity** (Waples 2005). To fully assess risk of extirpation from the San Joaquin basin from a qualitative perspective, I would add additional risk factors to the ones listed in the report: (5) high volatility in abundance, (6) low carrying capacity, (7) susceptible to Allee effects, (8) high correlation among sub-populations, and (9) position at edge of geographic range. Each of these additional factors lends support to the argument made in the Report that the SJB fall Chinook salmon ESU is at high risk.

(1) Lack of Diversity and/or Spatial Extent

It is important to note that three other runs of Chinook salmon (as well as one other listed species, green sturgeon) have already been extirpated from this river basin in recent times, yet these populations have persisted in the adjacent Sacramento basin. Chinook salmon diversity in run timing has clearly been reduced as a result. Diverse migration timing increases overall population viability. Two contributing risk factors are described below.

a. **Population synchrony**: Spatial diversity is thought to reduce metapopulation exposure to catastrophic events (Hilderbrand 2003). Rescue of one tributary by its neighbors during periods of low abundance is made less likely by the tight correlation among spawner abundances in the three SJB tributaries, the nearby Mokelumne River, and hatchery sub-populations (see figure 20 in Lindley et al. 2009). Shared exposure during estuary and ocean residence also produces correlation and increase shared susceptibility to catastrophic events (Botsford and Paulsen 2000).

b. **Geographic position/range contraction**: Species are more susceptible to extinction at the edges of their geographic ranges, and this has been shown for fishes (Gotelli and Taylor 1999). Because the SJB ESU represents the southernmost population of fall Chinook salmon, range contraction is a concern. Lack of metapopulation support from the south is one mechanism. Global (or local) warming could be another. In addition to spatial range contraction, this basin has also experienced temporal contraction (fewer runs).

(2) Demographic Risks (abundance, productivity).

Population dynamics for salmon are squeezed between a lower threshold population size below which population growth is negative (due to "Allee" effects) and upper threshold sizes above which habitat is saturated and density dependent effects lead to declines. Adding fluctuations to a narrow range of feasible population sizes can contribute to a high risk of extinction.

a. **Low carrying capacity**: In PVA models of salmonids, a low carrying capacity increases extinction risk (Hilderbrand 2003, Lindley and Mohr 2003). Strong over-compensatory density limitation increases volatility and even compensatory density dependence can push numbers fluctuating around an "equilibrium" down closer to the point of no return. In the SJB data, the peak returns observed in the early 2000's were not sustained by the next t+3 generation, suggesting that habitat limitation contributes to risk for the SJB ESU.
b. **Allee effects**: Some populations are unable to increase when they reach a threshold of low abundance (Dennis et al. 1989; Dennis 2002) and such thresholds can be important in assessing risk (Staples and Taper 2006). Myers et al. (1995) demonstrated that Pacific salmon stocks were among a small group of fishes that exhibited significant depensation (i.e., a tendency to decline below a threshold population size). In the absence of an Allee effect, McElhaney et al. (2000) suggest that populations should show evidence of increase in the generation (t+3) after a generation in year t with low numbers. This has not been evaluated for the SJB ESU.
c. **Volatility**: High year-to-year variability is an important measure of extinction risk (see Staples et al. 2004). Even a population with an increasing trend can reach extinction if year-to-year fluctuations are large. Semelparous species have periodic dynamics even without any environmental drivers, and variability in Pacific salmon abundances is known to be high (Paulsen et al. 2007).

Assessment of flow-salmon relationships

Section 3 of the report establishes that changes in the flow regime of the San Joaquin River basin are impairing fish and wildlife beneficial uses (**Table 1, #2**). In particular, it defends the view that a larger proportion of unimpaired flows in the SJB are required to prevent the extirpation of fall Chinook salmon. Three aggravating factors that previously contributed to declining numbers have recently been mitigated to some extent. These include availability of spawning gravel, mortality at export facilities in the Delta, and harvest. By a process of elimination, flow remains as a leading causal factor to consider. One physical manifestation of the decrease in flow in some places is a perched remnant historical floodplain with no chance of flooding, and formation of a new, lower floodplain (report; Opperman et al. 2010). Temporally, spring is the season during which regulated flows deviate most from unimpaired flows. Spatially, a smaller proportion of Vernalis flows now come from the three salmon-bearing tributaries (Merced, Tuolumne, and Stanislaus rivers).

The crux of the argument for increasing environmental flows in the SJB put forth in the report are observed positive associations between flow and fall Chinook salmon. Observed relationships include (1) that observed between winter and spring river flows at Vernalis and adult returns 2.5 years later (TBI/NRDC 2010 Exhibit 3; Speed 1993), (2) that between flow and survival of tagged juveniles migrating through the lower SJ river and estuary to Chipps Island, and (3) that prior to migration, between juvenile growth and ephemeral inundation of floodplain habitat. Flow influences on incubation survival were not specifically addressed in the report, but a few suggestions regarding the egg and alevin life stages are also presented below for possible consideration.

Parr/fry rearing. The report cites recent studies that have demonstrated benefits of floodplain rearing for fall Chinook salmon. It has long been recognized that floodplains provide refuge from aquatic predators, and serve as important nursery areas for many fishes (Welcomme 1979; Sparks et al. 1998). Brown et al. (2002) reported that salmon smolts are larger in coastal rivers with lower gradients and larger floodplains. Several studies have now shown a growth benefit to rearing in seasonally inundated floodplains in California rivers. Sommer et al. (2001a,b; 2005) demonstrated that juvenile Chinook salmon grew faster in the floodplain (Yolo Pass, Sacramento River) than in the main channel. The availability of preferred invertebrate prey was shown to be higher, and elevated temperatures likely also contributed to faster growth. Jeffres et al. (2008) reared juveniles in enclosures and observed fastest growth in ephemeral floodplain habitats than in either permanent floodplain or river). Henery et al. (2010) replicated these results and also observed even faster growth in free-ranging juveniles with coded-wire tags. These results are consistent with the results of a study of flood-pulse effects on invertebrates in the Tuolumne River, which showed a reduction in dominance by less-preferred dipterans and an increase in EPT taxa following a flooding event (Holmquist and Schmidt-Gengenbach 2009). The presence of established riparian vegetation was an important mediator of these benefits (Jeffres et al. 2008). Although it stands to reason that faster achievement of smolt size should result in higher survival (lower predation risk, accelerated salinity tolerance, exit prior to high temperatures), increased survival has not yet been demonstrated conclusively in the field (Sommer 2005). The size-survival relationship is however, well supported by other studies and future research with more statistical power will probably demonstrate a survival advantage. Based on the research presented in the report, I concur that providing floodplain inundating pulse flows during Feb-April would be a very worthwhile experiment for this river basin. As added support, I recently incorporated the growth advantages of floodplain inundation in a simplified fall Chinook model (Jager 2011). Although preliminary, optimal flow regimes produced by this exercise suggest a higher-than-expected value of pulse flows in late-winter, allowing smolt to leave the system earlier.

SJ smolt to adult return. Positive relationships have been demonstrated between the spawner return ratio from CWT releases in the San Joaquin mainstem and flow 2.5 years previously (Speed 1993). A more recent analysis found a significant positive logistic relationship between an indicator variable (increase or decrease in the cohort return ratio) and flow at Vernalis (TBI/NRDC 2010; Exhibit 3). One important feature of both the Speed and TBI models was that they considered returns at time-t per spawner at t-3 as the dependent variable, and not just spawner returns. This is important because the number of spawners that return is biologically constrained by the original number produced in the previous generation. I did not consider other analyses presented in the report that lacked this feature. The use of logistic regression in the TBI was also a good idea because the resulting model will be robust to extrapolation beyond the range of historical flows. However, the analysis was conducted recently and has not yet undergone scientific peer review and I would encourage them to complete this step in the process. In anticipation, they might explore whether the following refinements might reduce uncertainty in the flow threshold: 1) if there is enough data/power, consider expanding the analysis to include other covariates (e.g., return cohort A, B, C; initial spawner abundance); if not, consider quantile regression as a way to reduce influence of covariates not included (see Jager et al. 2010), 2) consider residual autocorrelation, and 3) evaluate whether it is possible to solve directly for the inflection point as a parameter, which would provide confidence bounds on the flow threshold. I would not expect these refinements to alter the main conclusions of the analysis.

SJ smolt to Chipps Island. Smolt were released at Mossdale, Dos Reis, and Old River and recaptured at Chipps Island. Smolt releases in the lower river have been conducted for quite a few years, before and after use of barriers. Paired releases were used to increase the statistical power of these studies. Transit times of survivors ranged from 5 to 21 d (11 d average) (Baker and Morhardt 2001) but the total duration of estuary residence is longer, on the order of ~40 d (MacFarland and Norton 2002). Understanding the relationship between freshwater flows and survival during migration is complicated by the fact that flow often operates indirectly through its effects on intermediate factors that directly influence survival (Speed 1993). In the Bay-Delta, these include temperature, dissolved oxygen (DO), salinity, and predation. A series of sophisticated statistical analyses attempted to separate the correlated effects of river flow, release temperature, and salinity using ridge regression, hierarchical Bayesian and non-Bayesian methods (Baker et al. 1995; Baker and Morhardt 2001; Newman and Rice 2003, Newman and Brandes 2005). Inclusion of temperature and salinity as direct causal pathways reduced the predictive capability of the indirect pathway (flow) (pre-2008 analyses) or vise-versa (Newman 2008). There is little doubt that the complex of flow-related influences collectively explains the majority of variation in smolt survival. From a management standpoint, it may be important to understand the proximate mechanisms responsible for the benefits of flow so that constructive options that require lower environmental flows can be considered.

Two remaining flow-influenced factor have not been included as covariates in models of survival during outmigration cited in the report. These are predation and low DO from the Stockton Deepwater Ship Channel

(Mesick 2009, page 3-32). Studies to coordinate water quality monitoring during smolt releases might help to understand the importance of water quality. Assessing predation might be a greater challenge. Higher flows can reduce predation risk by allowing smolts to occupy a larger volume of water (Bowen et al. 2009), by increasing turbidity (pulse flows), and by decreasing temperatures (Connor et al. 2003). Predators are able to consume and process more prey when temperatures are higher (Vigg and Burley 1991). Vogel et al. (2010) recently found that a large fraction of telemetered smolts were eaten by striped bass while transiting the estuary, although these unfortunate fish might have been impaired by surgically implanted devices. One counter argument, made by MacFarlane (2010), is that growth of sub-yearling Chinook salmon during the first month following ocean entry is faster when salinity is higher, thereby reducing ocean mortality during this time. However, Lund et al. (2008) question the assumption that freshwater outflows are the main controlling factor for salinity gradients in the San Francisco Estuary and highlight the role that habitat complexity can play.

The report has little to say about the role of flow during spawning and incubation. Cain et al. recommend sufficiently high, but stable flows during winter incubation presumably to avoid dewatering or scouring of redds, and this was also the solution found by our salmon-flow optimization for the Tuolumne (Jager and Rose 2003). However, research is needed to understand flow effects on survival, which is lower in SJ tributaries than in the Columbia River (Geist et al. 2006) at similar temperatures. Siltation and low DO may account for this difference and may be mitigated by increasing flow/depth to increase exchange (downwelling) with hyporheic flow (see Tonina and Buffington 2011).

Proposed flow regimes

The report does a good job of presenting the natural flow paradigm and highlighting the inadequacy of past approaches focused on supplying minimum flows. The approach used to support flow objectives is appropriate and should protect fall Chinook salmon (**Table 1, issue #3**). The report puts forward the science supporting the need for a higher percentage (60%) of unimpaired flow with a seasonal shape similar to that of unimpaired flows. Similar efforts to restore a natural flow regime and/or reconnect rivers with their floodplains have been applied in the Missouri River (Bovee and Scott 2002) and elsewhere in the US (Opperman et al. 2010).

The report does not present one specific proposed flow regime, but rather advances guidance from other studies, and these seem to be in general agreement. The authors cite several studies in which more-specific guidance was developed for spring flows (e.g., Cain et al. 2003; TBI/NRDC 2010 Exhibit 3). The TBI/NRDC analysis recommended spring flows of 4,600 cfs (130 cms) or higher at Vernalis. If the proposed 60% of unimpaired SJR flow at Vernalis were followed for March-June, this threshold would be met or exceeded in >85% of years. The report established the basis for requiring a more natural pattern of flows in the three SJ tributaries during Feb-June to restore salmon and steelhead (**Table 1, issue #4**). Recent degradation of water quality in fall and spring in the lower SJ may in fact require high flows during critical periods than were historically observed, and it is fortunate that the storage capacity in rim dams will allow this compensation.

In the last part of Section 3, the report indicates that the SWRCB will also consider percentages of unimpaired flow as low as 20% in order to accommodate competing water demands. It is unclear to me how a percentage of even 40% would be an improvement over current median (44%) and average (48%), as I understood them from Table 2.3 in Section 2 (**Table 1, issue #5**). The basis for instituting lower percentages than are currently provided was not justified in Sections 2 and 3 of the report and seems counter-indicated by the rest of the analysis presented. However, supporting information may appear later in the Water Supply section of the report (Section 5), which I did not review.

The report was careful to emphasize that as new knowledge is gained, the management of river flows should be adjusted. The Cain et al. holistic analysis went well beyond describing the statistical flow duration curve, providing a careful assessment of how timing of flows relates to specific ecological objectives. The Cain et al. report identified flow thresholds to support channel migration, sediment mobilization, and inundation of floodplains. Their approach considered a variety of important processes through which flow influences salmon. Geo-morphological processes in low gradient rivers create slow, shallow connected floodplain habitat, which is increasingly recognized as an important component of habitat diversity for aquatic ecosystems (Trush et al. 2000; Galat et al. 1998; Galat and Lipkin 2000; Jacobson and Galat 2006). Shading by riparian vegetation help to provide refuge from high temperature (Seedang et al. 2008) and predators. The role of floodplain and shallow habitat as nursery areas for fishes (e.g., Bowen et al. 2003) was considered by including flows that inundate floodplains.

One consideration in deciding how to shape rearing and migration flows is the possibility that shorter pulses are more effective than persistent flooding. This aspect was not specifically addressed by the report. For example, studies have shown that shorter pulses stimulate juvenile outmigration (Cramer 1997; Demko & Cramer 2000). One study found floodplain inundation to be more effective when it is intermittent because vegetation growth is promoted (Jeffres et al. 2008). The presence of vegetation may reduce loss of invertebrate production when floodplains are drained. An experimental framework to examine duration effects may be needed.

Following past practice, the report describes prescribed flows developed by Cain et al. distinguish different targets by hydrologic year types. Hydrologic year types were defined by quantiles, an improvement over arbitrary past designations. To summarize recommendations, in wetter years (<20-50% exceedence), the holistic analysis provided for bed-mobilization flows, channel migration flows and flows to support riparian regeneration. Adequate fish passage flows are recommended in all but the driest years (>80%). Attraction flows and flows for salmon outmigration were included for all hydrologic year types (Cain et al. 2003). The assumption above is that wet years should be used to meet objectives that are expensive in terms of flow. Providing a higher percentage of unimpaired flows will go farther to avoid losing cohorts to extended droughts. However, from the perspective of salmon-demographics, there may be value in using a cohort-based approach (A, B, C in the report, where cohort A spawn in years t, t+3, t+6,…, [t+3]*k and cohort B spawn in years t+1, t+4, etc…).

The report listed proposed regulated schedules for flow, but did not go very far in the direction of proposing specific future flow schedules or processes for defining them. In theory, once an annual percentage is set, four options can be considered or combined to design seasonal flows to better support salmonids that can be translated into rules used in reservoir operation: 1) operate as what I would call “reduced run-of-river,” 2) follow guidelines proposed by Cain et al. and/or TBI/NRDC, 3) follow regimes determined by optimizations to maximize salmon production, or 4) conduct statistically designed experiments. Run-of-river operation for the reduced percentage of water is the simplest method for tracking the natural flow regime. One advantage of this approach is that it does not require fixing the temporal resolution at which a natural flow regime is mimicked.

Optimization methods provide a more formal approach to quantify direct and indirect pathways linking flow and salmon. Ongoing research has sought to optimize flow regimes with the objective of maximizing salmon production from SJ tributaries (Bartholow and Waddle 1995; Cardwell et al. 1996; Jager and Rose 2003; Jager 2011), or salmon diversity (Jager and Rose 2003). At least one study provided guidance for designing flows to establish riparian vegetation (Stella et al. 2011). Others have included environmental objectives as part of a broader multi-objective problem in California (Draper et al 2003; Lund et al. 2008; Null and Lund 2011). If it is important to consider competing water demands, then a formal optimization with adequate provision for objectives related to restoring Chinook salmon will be needed.

One final approach to consider is statistical design of flow experiments. Treatments to consider might include pulse flows during different seasons and with different durations and magnitudes. Experimental units might be the three tributaries and the three salmon cohorts (ABC).

Areas for further research into partially-non-flow mitigation options might include mitigating for DO in Stockton Channel during both migrations, floodplain 'design' to allow for inundation at lower flows, and providing enough flow to generate habitat complexity and refuge from predators.

In summary, the report established the risk to salmon and steelhead in the Central Valley and laid out the case for increasing the percentage of unimpaired flows released to the three salmon-supporting tributaries using research conducted in the Central Valley as well as other research relevant to the situation in California. The contention that a higher percentage of unimpaired flow is needed in late winter and spring was well supported by research. In this review, I have added references and information from the scientific literature that support the general conclusions of the report with regard to issues #1 through #4, but not #5 (Table 1).

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TBI/NRDC (The Bay Institute (TBI) and Natural Resources Defense Council (NRDC)). Exhibit 3. Written Testimony of Christina Swanson, Ph.D., John Cain, Jeff Opperman, Ph.D., and Mark Tompkins, Ph.D. Regarding Delta Inflows.

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